Facility Location Optimization for Last-mile Delivery

By: Brittany C Collins and Hao Wang
Advisor: Dr. Sergio Caballero

Topic Areas: Optimization, Last Mile

Summary: The final leg of transportation of goods to the end recipient, or the "last-mile," is of increasing importance to freight services companies. This project explored the tradeoff between facilities' costs and the implied savings on transportation costs. We used center of gravity analysis and mixed-integer linear programming to recommend an alternative network of facilities which reduced overall costs compared to the existing network.

Prior to MIT, Brittany Collins worked as business analyst in multiple divisions of United States Steel Corporation. She received her Bachelor of Science from Saint Vincent College in Latrobe, Pennsylvania.

Prior to MIT, Hao Wang worked as a supply chain consultant at DHL Consulting in Singapore. She received her Bachelor of Engineering and Bachelor of Business Administration from National University of Singapore.

KEY INSIGHTS

1. **The largest step-change in reducing the average mileage to serve a customer occurs when the first incremental facility is added in a market**
2. **Transportation cost savings outweigh the incremental facilities' costs, given competitive market rates**
3. **Optimization is one tool when considering network design changes; qualitative factors should also be discussed**

Introduction

Technological breakthroughs and consumer preferences have led to e-commerce growth in the United States. With more consumers buying online and requesting delivery straight to their doorstep, freight services companies are frequently dealing with the challenge, complexity and cost of servicing the last-mile.

The project sponsor's existing freight services' network includes one cross-docking facility per metropolitan area, resulting in long "stem-time" to service the customer. The research hypothesis was that creating a more strategically-located network of cross-docks, each more proximal to common delivery points, would generate cost efficiencies through a reduction in overall travelling distance. The research approach would be to build an optimization model and compare the proposed network's facility and transportation costs to the existing network's costs.

Methodology

In order to test the research hypothesis, we first needed to establish a baseline. We began by collecting 12 months of shipping data, including transportation costs, for seven of the company's major markets: Atlanta, Chicago, Dallas, San Francisco, Los Angeles, Newark and New York. We also had the square footage and capacity of the seven existing cross-docking facilities.

We next mapped out our overall methodology, shown in Figure 1. Before we could begin modeling, some data cleansing and aggregation needed to occur. Given that last-mile deliveries to customer homes will continually evolve and change, it was necessary to aggregate customer demand instead of using individual addresses. We aggregated to 5-digit zip codes.

The first model was Center of Gravity (COG). COG provides a recommended facility location based on minimizing the weighted average distance to all

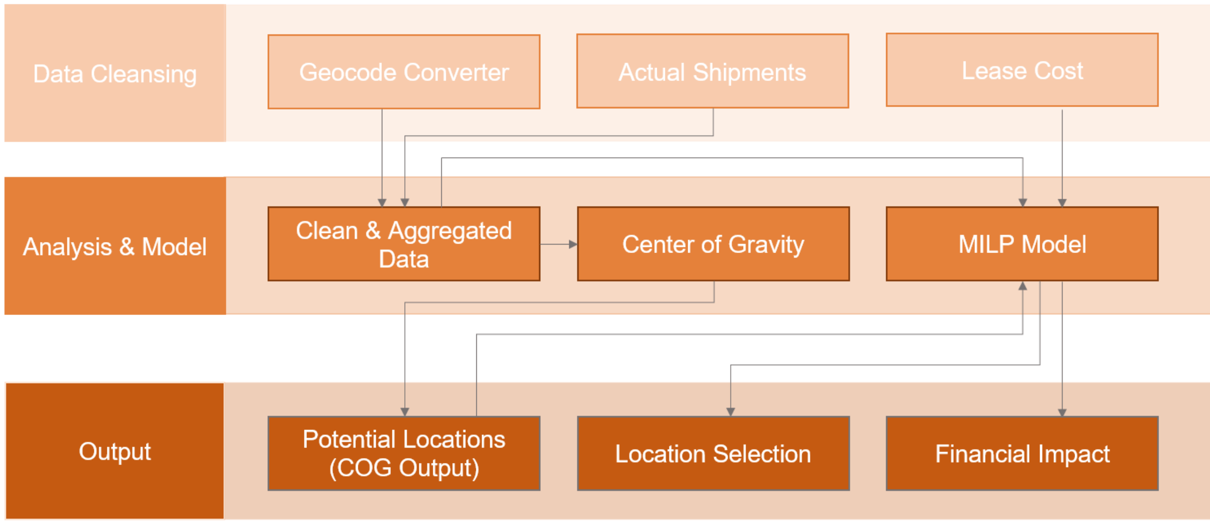


Figure 1: Methodology Process Steps

demand points (5-digit zip codes). COG analysis does not include cost, and therefore could not address the hypothesis, but it was used to generate new cross-docking facility nodes in each of the seven metropolitan markets. The COG-generated facility nodes would be used as an input in our second model.

The second model was Mixed-Integer Linear Programming (MILP). The benefit of MILP is that its objective function minimizes cost; therefore, the model's results could be compared to the baseline costs and respond to our research hypothesis. The two cost components we used were facility cost and transportation cost. The company leases its cross-docking facilities, so we collected facility lease costs in $/sqft/yr from the company's real estate agency based on the facilities' zip codes. The transportation costs were calculated based off of the original dataset, but a new $/lb/mile average was calculated for each metropolitan area to reflect the lane cost from the new facilities to the 5-digit zip code demand nodes.

Across the seven metropolitan areas, the MILP had a total of 84 facility nodes to choose from. We did not place capacity constraints on the proposed facilities because they are leased and capacity was not enough of a concern to constrain the model. The facility costs, however, did reflect the assumed square footage needed to meet the demand allocated to the facility. We ran two different scenarios for each region:

- Scenario 1: Site location unrestricted; model can choose from any facility node in the market
- Scenario 2: Includes the company's existing facility, and cost-optimizes other sites

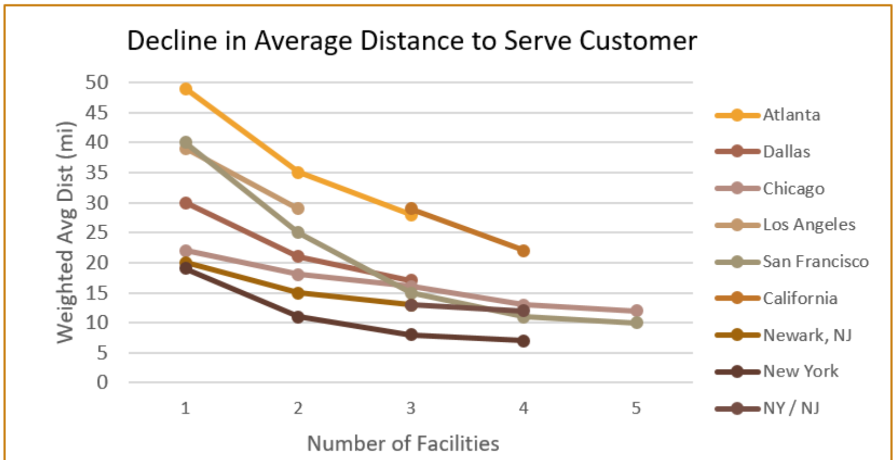
Scenario 2 was considered the more likely scenario if the company were to move forward with changing their distribution network.

The methodology outlined was a clear two-model process which would lead to several results the company desired. The COG would provide initial insight into facility locations and seed the MILP. Ultimately, the cost-inclusive results from the MILP would spark management discussion on optimizing last-mile delivery for the company. Those results are discussed next.

COG Analysis Results

For each region, we utilized COG analysis to solve for one location which allowed us to see how close the existing facility was from the optimal demand-distance location. Next, we increased the number of facilities serving each market, for a total of 29 different scenarios. Figure 2 depicts the impact that additional facilities had on the weighted average. As the graph depicts, the greatest incremental reduction in miles occurs in the first facility addition beyond the baseline number of facilities. Additional facilities were at diminishing returns.

We used the COG facility scenarios to decide how many facility nodes per metropolitan area we would have the MILP select. As the table in Figure 2 depicts, we proposed a two-station solution for Atlanta, Dallas, and Chicago. Due to the proximity of demand and overall network distance benefits, we would combine



Atlanta	49	35	28		
Dallas	30	21	17		
Chicago	22	18	16	13	12
Los Angeles	39	29			
San Francisco	40	25	15	11	10
California			29	22	
Newark, NJ	20	15	13		
New York	19	11	8	7	
NY / NJ			13	12	

Scenario not run

Selected

Figure 2: COG Facility Scenarios

the San Francisco and Los Angeles markets into "California," and the Newark and New York City markets into "NY/NJ."

MILP Model Results

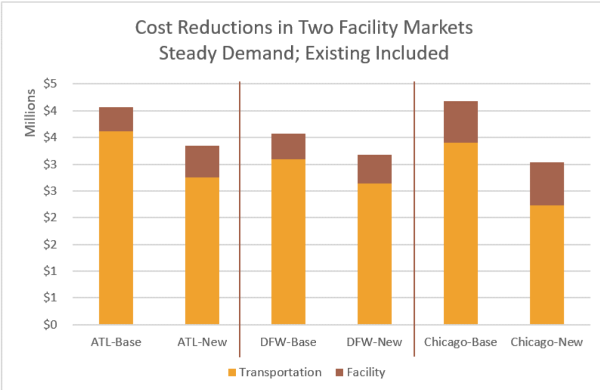
The MILP model generated the cost information we needed to test the research hypothesis. Although we ran two scenarios for the each of the five locations (Atlanta, Dallas, Chicago, California and NY/NJ), the results summarized here are for the second scenario when we forced the MILP to use the company's existing facilities.

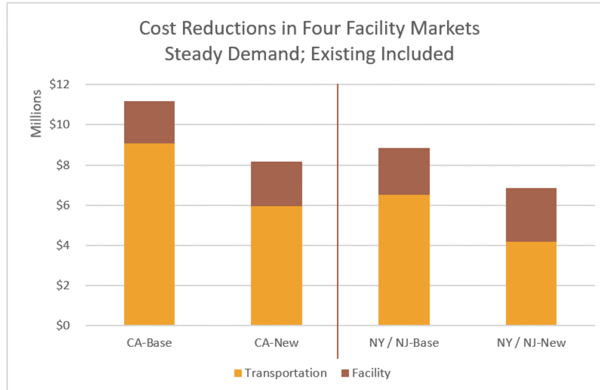
The first observation we made from the MILP results was the location of cross-docking facilities. Because the MILP objective function is set to minimize cost, the facility cost was reduced by $4/sqft/yr when compared to the company's existing lease rates.

The second observation we made was facility capacity utilization, given that additional facilities were added to network. This question was of interest to the company because they experience seasonality and wanted a sense of how the MILP allocated volume. The result was in line with the company's expectations. For most of the year, the capacity utilization was around 80%, but during the end-of-year holiday season, the utilization exceeded 100%, meaning the company may need to outsource or offload shipments to another facility.

The third observation was related to the transportation. The new network had a total of 14 facilities compared to the baseline which had 7. We wanted to compare the difference in weighted average distance (miles) to serve a customer node (5-digit zip code) in the new network compared to the baseline. The overall reduction was 14 miles. Additionally, the company incurred extra costs when a customer resided 50 miles or greater from a facility, so they were curious how fewer customers met that criteria in the new network. Overall the percent of customers greater than 50 miles decreased from 15% to 8%.

Finally, fueled with an understanding of what changed in the facilities on a dollar-per-square-foot basis and the transportation on a mileage basis, we looked at the total cost benefits shown in Figure 3. Responding to the research question, we could say that based on the costs and assumptions provided, adding additional facilities to the network would reduce the cost of transportation, by reducing the overall mileage to serve the customers, and could result in a total cost savings around 23%.





	Facilites		Transportation Cost			Facility Cost			Cost Benefit	%
Airport	Baseline	New	Baseline	New Cost	Difference	Existing	New Facility	Difference		
Atlanta	1	2	$3,620,992	$2,755,852	($865,140)	$445,500	$595,500	$150,000	($715,140)	-18%
Dallas	1	2	$3,088,468	$2,646,510	($441,958)	$489,750	$527,750	$38,000	($403,958)	-11%
Chicago	1	2	$3,401,641	$2,226,286	($1,175,356)	$771,750	$807,750	$36,000	($1,139,356)	-27%
California	2	4	$9,056,727	$5,936,968	($3,119,759)	$2,112,750	$2,251,500	$138,750	($2,981,009)	-27%
NY / NJ	2	4	$6,505,908	$4,185,976	($2,319,932)	$2,357,000	$2,679,500	$322,500	($1,997,432)	-23%
Total	7	14	$25,673,736	$17,751,592	($7,922,144)	$6,176,750	$6,862,000	$685,250	($7,236,894)	-23%

Figure 3: MILP Cost Benefits when Existing Facilities Remain in New Network

Conclusions

While we are certain that the resulting cost benefits are directionally accurate, there are limitations to keep in mind when observing the results. We have provided suggestions for furthering the analysis.

First, we have a rather high level of confidence in the facility lease rates ($/sqft/yr); however, we assumed these rates would scale linearly. It is possible that some of the suggested locations will not accommodate the square footage needed to process the volume allocated to the facility, or that the market rate may be different for a larger or smaller facility depending on the location.

Second, there are other costs which are important to consider if the company continues analyzing their delivery network. Some costs to consider are: additional labor cost, new equipment rentals, maintenance, as well as other overhead costs from operations.

Lastly, we encourage that a cross-functional team be engaged in this strategic network decision to grapple with the qualitative implications of adding facilities. Some questions which may arise in discussion are:

- What complexity will additional facilities add to the allocation and routing problems?
- How fast can the company's IT planning systems be modified to integrate additional nodes?
- Will retail partners be willing to increase drop off points to the new facilities?

This research project was conducted using widely accepted network optimization methods of COG and MILP. We were pleased that these methods addressed the company's research question, providing insight into the stem time by measuring average miles and percent of customers greater than 50 miles, and demonstrated high-level cost benefit analysis.